

SURVEILLANCE MEASUREMENTS WITHIN CALIFORNIA'S DAM SAFETY PROGRAM

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Abstract: The review of instrumentation schemes and data is one part of the State of California's supervision of dams and reservoirs. This activity is based on policy enumerated in the Water Code. Implementation of this policy is detailed in the administrative procedures of the Department of Water Resources and its Division of Safety of Dams. Recent examples illustrate the functioning of this program and validate the basic approach of (1) the State determining the minimum level of surveillance required for safety for each dam on an individual basis at the design stage of the project, (2) collection and timely evaluation of instrumentation data by dam owners, (3) State review of the owner's surveillance activities at up to 12 month intervals, and (4) emphasis in the State's program on periodic inspections supplemented by review of instrumentation data.

INTRODUCTION

Surveillance measurements of dams in California are the responsibility of the owner and are subject to supervision by the Department of Water Resources, as specified in the State Water Code. The review of owner transmittals of surveillance data plays a significant part in the State's dam safety program, serving to supplement the primary State surveillance activity, periodic inspections.

AUTHORITY OF DIVISION

Division 3 of the California Water Code constitutes the State's statutory authority for the supervision of dams and reservoirs. Article 2 of Division 3 is the relevant statute pertaining to surveillance measurements. It consists of three paragraphs, Sections 6100, 6101 and 6102. References to instrumentation are indirect.

Section 6100 says:

"Supervision over the maintenance and operation of dams and reservoirs ... is vested in the department."

The words "maintenance and operation" are understood to include surveillance programs. This section gives the Department of Water Resources the authority to regulate the surveillance measurements of dams and reservoirs.

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Section 6101 says the Department may at its discretion require dam owners to:

"keep records of, and report on maintenance, operation ... and shall issue such rules and regulations and orders as necessary to secure maintenance and operation ... which will safeguard life and property. In addition, the owner of a dam or reservoir or his agent shall fully and promptly advise the department of any ... unusual or alarming circumstance or occurrence affecting the dam or reservoir."

This section identifies the collection and timely evaluation of instrumentation data as a responsibility of dam owners.

Section 6102 says the expenses for instrumentation monitoring are paid by the owner:

"The department ... shall require owners to perform at their expense such work as necessary to disclose information sufficient to enable the department to determine conditions of dams and reservoirs in regard to their safety and to perform at their expense other work necessary to secure maintenance and operation which will safeguard life and property."

These then are the references to surveillance measurements in the Water Code.

Essentially, California dam owners are responsible for:

1. Instrumenting each dam at their own expense to the minimum required for safety, as determined by the State.
2. Collection of the surveillance measurements.
3. Timely evaluation of their measurements.
4. Transmitting to the State, at regular intervals, a copy of their surveillance measurements with an evaluation.

On the other hand, the State is responsible for:

1. Regulating dams and reservoirs to safeguard life and property including supervision of surveillance measurements.
2. Determining the minimum amount of instrumentation needed for each dam to safeguard life and property.
3. Verifying that each dam and reservoir is operated and maintained in a safe manner, including periodic review of the dam owners' surveillance programs.

THE ROLE OF SURVEILLANCE IN STATE SUPERVISION

High Priority

The importance of surveillance in California's Dam Safety Program can be seen from the number of staff committed to this function. The Division of Safety of Dams has committed one-third of its staff, the 20 engineers in the Field Engineering Branch, to make periodic inspections. These inspections include the review of an owner's surveillance program. An additional 4 engineers, in the Design Engineering Branch, have as their primary assignment the review of instrumentation data transmitted periodically by the owners. The Division's allocation of a large part of its staff to surveillance demonstrates the high priority assigned to this activity for safeguarding life and property.

Observation over Instrumentation

Another aspect of this allocation of staff for surveillance activities is the distribution between the number of engineers doing inspections and the number of engineers doing only reviews of instrumentation data, about 5 to 1. This distribution reflects the Division's emphasis on observation rather than instrumentation. Perhaps this philosophy has been best enunciated by Dr. Ralph Peck,

"An instrument too often overlooked in our technical world is a human eye connected to the brain of an intelligent human being. It can detect most of what we need to know about subsurface construction. Only when the eye cannot directly obtain the necessary data is there a need to supplement it by more specialized instruments. Few are the instances in which measurements themselves furnish a sufficiently complete picture to warrant useful conclusions."

In California, the emphasis with respect to surveillance is on regular inspections by Division engineers. Review of instrumentation data by the Division's design engineers supplements the firsthand observations of its field engineers.

Internal Check

Still another aspect of the Division's surveillance program is that the four engineers whose primary task is to review instrumentation data are not part of the Field Engineering Branch. Instead, they are part of the Division's Design Engineering Branch. This organization provides an internal check or second evaluation, within the Division, of the surveillance done by the Field Engineering Branch, in addition to providing the Field Engineers with detailed reviews of the instrumentation data.

TASKS OF DESIGN ENGINEERING BRANCH

The four engineers whose primary function is the review of instrumentation data are in the Engineering Services Unit of the Design Engineering Branch.

These four engineers do three kinds of work involving instrumentation. First, they evaluate the instrumentation scheme for a proposed dam during the design stage of the project. Second, they

review the regular submittals of instrumentation data and accompanying interpretation, received from dam owners. Third, they make special evaluations of changed or unusual conditions, usually at the request of the Field Engineering Branch. In each case, the results of the review are summarized in a memorandum report that becomes part of the permanent record maintained by the Division for that particular dam.

Design Review of Instrumentation Schemes

The plans and specifications for the construction of a new dam or for the repair or alteration of an existing dam are reviewed by the Design Engineering Branch including instrumentation. Each instrumentation scheme is evaluated on an individual basis considering dam size, type, complexity, foundation conditions, and other salient characteristics rather than using simplified charts or tables. The effectiveness of this approach is dependent in large part on the use of experienced and knowledgeable staff.

The assessment of surveillance needs; formulation of an instrumentation scheme; and documentation of the dam designer's assumptions, intent, and expectations in an instrumentation manual are done when most expedient - during the design stage of the project.

Reliance upon the informative publications of the Corps of Engineers, the Bureau of Reclamation, and others is readily acknowledged. An occasional reference to these publications in discussions with owners and their engineers has been utilized rather than producing and distributing a State standard that would essentially summarize this kind of information.

One aspect of this review, particularly for larger dams with more complex instrumentation schemes, is the State's requirement of an instrumentation manual. This manual primarily serves as a bridge between the designer of the dam and the operator of the dam. In brief, the manual includes design assumptions, the purpose of each measurement, predicted values, limits of acceptable behavior, accuracy of the measurements, data sheets and instructions for operation and maintenance of the instrumentation.

An example of this kind of review is the instrumentation scheme for a 190-foot high concrete arch dam that was designed by a private engineering company for an owner with a small engineering staff that had limited dam experience. The State required the following additions to the designer's surveillance program to achieve a minimum level of safety monitoring:

1. Measurement of reservoir water surface elevation.
2. Measurement of drainage and seepage flowrates.
3. A control network to provide a fixed reference frame for position control of the local survey network.
4. A recommendation for a simple system for rapid monitoring of deformations.

5. Detailed specifications and installation plans for each instrument.
6. An instrumentation manual providing the purpose of each measurement; predicted values and tolerance limits; the range, accuracy and precision of each measurement; data sheets; and instructions for the operation and maintenance of the instrumentation.

Also included was a recommendation for measuring the response of the dam to strong earthquake shaking. Except for the absence of strong motion accelerometers, the owner adopted the recommendations, including preparation of a detailed instrumentation manual and the installation of four plumb lines for rapid monitoring of deformations.

Routine Periodic Reviews of Instrumentation Data

During construction, during initial reservoir impoundment, and then for the life of the dam, instrumentation measurements are made and evaluated by the owner and transmitted to the State for review. Review of the surveillance data for a typical dam is made by both the owner and the State, and goes through the following steps:

1. Brief evaluations of new data by the owner each time it is collected.
2. A more thorough evaluation by the owner of data collected since the last transmittal to the State, including a written summary.
3. Transmittal of data and evaluation to the State.
4. Review by the State of the owner's data and evaluation, including an acknowledgement to the owner and a written report.

The interval between data transmittals to the State is determined during the design stage of the project. The transmittals are more frequent during construction and first impoundment than during subsequent operation of the dam and reservoir.

The information transmitted to the State is first reviewed in the Field Engineering Branch. Then, a more lengthy review is made by the Design Engineering Branch which includes preparation of a memorandum report. This report is routed back to the Field Branch, after which it is placed in the State's permanent file for that particular dam.

The review by Design Engineering Branch consists of a preliminary review, an acknowledgement to the owner, and a detailed review including preparation of a report.

The preliminary review is made in order to add to the acknowledgement letter to the owner any comments or concerns due to changed conditions indicated in the transmittal. If there are no extenuating circumstances, a standard acknowledgement letter is sent. If the data was transmitted without an evaluation, this deficiency is addressed in the acknowledgement. All nonstandard acknowledgement letters are routed through the Field Branch for approval.

The detailed review involves several steps. The owner's comments or evaluation are duly noted. The data is checked for completeness and continuity with the data on file. Are any measurements missing from the submittal? Is there coverage for the entire time period? If necessary, the data is prepared in a more suitable format for review, such as producing a graph of reservoir elevations and seepage pressures from a table of data. This may consist of adding to or updating a plot already in the file. Other information on current conditions in the State's permanent file is checked, particularly the correspondence file and recent inspection reports. The new surveillance data is reviewed from two perspectives. First, as a function of time to identify new or changing trends, such as an increased seepage flowrate. Second, with respect to design assumptions, such as the relationship between measured piezometric pressures and the design flownet. These two perspectives form the basis for evaluating current conditions. Conclusions with respect to safety are then formulated. The review is summarized in a report, typically 1 to 3 pages, explaining its purpose, pertinent information from recent inspections and correspondence, identification of any missing data, separate discussions of the dam's behavior as indicated by each type of measurement, and an overall summary of the general conditions indicated by the data. A series of these reports for a particular dam forms a record of that dam's performance and behavior.

One example of the State's review of a routine submittal is the November 1988 transmittal for a 200-foot high embankment dam. One year of piezometer and drainage measurements were submitted without a written evaluation. The State's acknowledgement letter to the owner included a request that future data transmittals include an interpretation of the data with respect to safety of the dam. The Design Engineering Branch review identified seepage pressures in the downstream toe area that had increased up to 11 feet so that artesian conditions corresponding to a factor of safety against piping/internal erosion of 1.0 now prevailed. A phone call to the owner revealed that the readings were erroneous. The seepage pressures were unchanged. The potentially unsafe condition was fictitious. This example shows how the State's supervision of the owner's surveillance programs can identify serious deficiencies that can be easily corrected before a problem develops.

When an owner fails to make timely evaluations of the surveillance measurements, the safety monitoring has become ineffective and can only lead to a dangerous sense of false confidence. In such situations, the State's function is to educate the owner regarding the importance and significance of their role. The following is an example of the information that is conveyed in these circumstances:

1. Dam surveillance is the owner's responsibility, as specified in the California Water Code.
2. Dam owners, who make surveillance measurements monthly, weekly, and even daily are in the best position to make timely assessments of current conditions. The State typically makes inspections and data reviews either annually or semiannually. Dam owners are more familiar than the State's engineers with both the behavior of their respective dams and with local day-to-day occurrences that might have a bearing in assessing safety.
3. Surveillance of 1200 jurisdictional dams by the 46 engineers in the State Division of Safety of Dams cannot substitute for ongoing monitoring by each owner.
4. The owner's timely review of surveillance data is vital to assure the continued safety of the dam.

Consider the example of another owner which illustrates a more responsible attitude and effective program. Dams belonging to this owner include a 188-foot high embankment, located in an urban area with a large population downstream. The regular surveillance transmittal of December 1987 to the State for this dam called attention to a sudden 19-foot increase in seepage pressure within the embankment, indicated by an observation well at the dam crest. No anomalous behavior was indicated by the other instrumentation. Although the primary effect on safety of the higher seepage pressures was only a small reduction in slope stability (a change in factor of safety against sliding from 2.9 to 2.7), the owner installed 4 new observation wells in June 1987 and 4 more observation wells in May 1988. Both sets of new wells were installed to provide more coverage of the phreatic surface in the embankment. The new wells confirmed the higher seepage pressure. Seepage pressures continue to rise, but at a slow rate. At present, the cause of the changed conditions has not been determined. However, both the owner and the State have determined that the new conditions do not constitute a threat to life and property. Such close surveillance by an owner helps to insure the continued safety of the general public.

Another example illustrates how instrumentation data can identify where to direct additional attention. Since 1982, the owners' 6-month surveillance transmittals to the State for this 172-foot high embankment have noted small, but measurable movement of the downstream slope, not at all unusual. The reviews by Design Engineering Branch initially identified the overall movement as downhill, and then identified a pattern consistent with the beginning stages of a slide, including bulging at the toe and movements accelerating with time. Although the movement rate has now been accelerating for 2 years, the maximum movement to date is only a quarter of a foot. Inspections of this slope have shown no corresponding visible changes. The final outcome of this behavior has yet to be determined.

Another aspect of these routine reviews deserves mention. Because most dams do not have safety problems, an irresponsible reviewer could make only superficial evaluations of the data without mishap for a considerable length of time. It is important, therefore, that the reviews be done in a careful, conscientious and thorough manner. Only then can the exceptions, the anomalies in the data that may portend a problem, reasonably be expected to be identified.

Special Reviews of Anomalous Behavior

Reviews of anomalous behavior indicated by instrumentation data are made as the need arises.

One example is the review of increased seepage at a 187-foot high embankment dam in an urban setting. The owner had notified the State that the toe drain flowrate had increased from a normal range of 10 to 60 gallons/minute up to an estimated 400 gallons/minute. This drain is at the upstream toe. It conveys the seepage collected by the drainage zone beneath the upstream impervious lining. Evaluation of reservoir level, toe drain, underdrain, and observation well data showed that only the toe drain flowrate indicated a change in behavior. Because of the variation in reservoir level, the toe drain flowrate also showed considerable fluctuation. By plotting toe drain flowrate versus reservoir elevation, the normal flowrate was determined for a range of reservoir elevations. This plot was used to identify when the behavior changed. There were no significant events or external influences, such as an earthquake, that corresponded to this date. The changed behavior consisted of 6 weeks at 3

times the normal flowrate followed by a jump to about 10 times the normal flowrate. At this point the owner was slowly drawing down the reservoir and had begun investigations to identify the cause. As the reservoir level dropped, the flowrate decreased. The instrumentation review was unable to identify the cause of the changed behavior from the information at hand, but speculated that there was a hole a few inches in diameter in the upstream lining at about Elevation 800 feet. Subsequent investigation in the field found the leak, a 5-inch diameter hole at Elevation 792.5 feet. The leak was repaired and the dam and reservoir returned to service.

SUMMARY

The role of surveillance measurements in California's dam safety program supplements the more extensive inspection activities. Review of the information obtained from dam owners' instrumentation programs is a significant part of this State's program to safeguard life and property.

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